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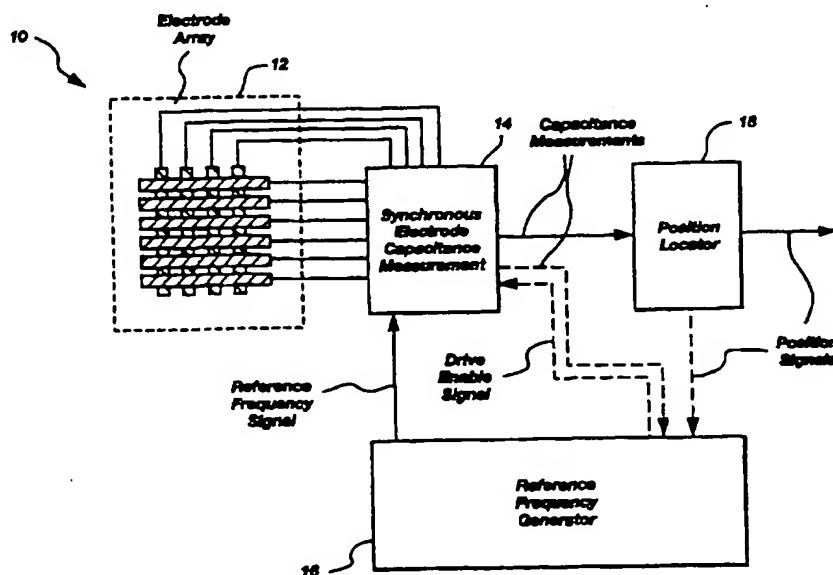
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(54) Title: CAPACITANCE-BASED PROXIMITY SENSORS WITH INTERFERENCE REJECTION APPARATUS AND METHODS



(57) Abstract

Apparatus and method for a capacitance-based proximity sensor with interference rejection. A pair of electrode arrays (90) establishes a capacitance on a touch detection pad (12), the capacitance varying with movement of a conductive object near the pad (12). The capacitance variations are measured synchronously with a reference frequency signal to thus provide a measure of the position of the object. Electrical interference is rejected by producing a reference frequency signal which is not coherent with the interference.

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**CAPACITANCE-BASED PROXIMITY SENSORS WITH
INTERFERENCE REJECTION APPARATUS AND METHODS**

10 This invention relates generally to apparatus and methods for touch sensitive input devices, and more particularly, to apparatus and methods for capacitance-based touch detection wherein electrical interference is effectively rejected from the detection system.

15

BACKGROUND OF THE INVENTION

Numerous prior art devices and systems exist by which tactile sensing is used to provide data input to a data processor. Such devices are used in place of
20 common pointing devices (such as a "mouse" or stylus) to provide data input by finger positioning on a pad or display device. These devices sense finger position by a capacitive touch pad wherein scanning signals are applied to the pad and variations in capacitance caused
25 by a finger touching or approaching the pad are detected. By sensing the finger position at successive times, the motion of the finger can be detected. This sensing apparatus has application for controlling a computer screen cursor. More generally it can provide
30 a variety of electrical equipment with information corresponding to finger movements, gestures, positions, writing, signatures and drawing motions.

In U.S. Patent No. 4,698,461, Meadows et al., a touch surface is covered with a layer of invariant
35 resistivity. Panel scanning signals are applied to excite selected touch surface edges so as to establish

an alternating current voltage gradient across the panel surface. When the surface is touched, a touch current flows from each excited edge through the resistive surface and is then coupled to a user's finger (by capacitance or conduction), through a user's body, and finally coupled by the user's body capacitance to earth ground potential. Different scanning sequences and modes of voltage are applied to the edges, and in each case the currents are measured. It is possible to determine the location of touch by measuring these currents. In particular, the physical parameter which indicates touch location is the resistance from the edges to the point of touch on the surface. This resistance varies as the touch point is closer or farther from each edge. For this system, the term "capacitive touch pad" may be a misnomer because capacitance is involved as a means of coupling current from the surface touch point through the user's finger but is not the parameter indicative of finger position. A disadvantage of this invention is that accurate touch location measurement depends on uniform resistivity of the surface. Fabricating such a uniformly resistive surface layer can be difficult and expensive, and require special fabrication methods and equipment. The panel of the Meadows '461 patent also includes circuitry for "nulling", or offsetting to zero, the touch currents which are present when the panel is not touched. This nulling can be accomplished while the panel operates, and allows touches which generate a relatively weak signal, such as from a gloved finger, to be more accurately determined. The Meadows '461 panel also includes circuitry for automatically shifting the frequency of panel scanning signals away from spectra of spurious signals, such as those developed by cathode-ray tube transformers, which may be present in the environment. The panel seeks to avoid interference from the spurious signals, which could happen if the

frequency of scanning was nearly equal to that of the spurious signals. A microcontroller determines whether the scanning frequency should be shifted by monitoring the rate at which adjustments are required in nulling of the touch currents, as described above. The only means described for generating frequency control signals is based on this nulling adjustment.

U.S. Patent No. 4,922,061, Meadows et al., is similar to the Meadows '461 patent in that the touch panel determines touch location based on variations in resistance, not capacitance. This is particularly evident from FIG. 2 where the resistances from edge to touch point are shown as Kx times Rx , where Kx corresponds to the distance indicated by 76A. The apparatus uses a measurement signal of a frequency that varies in a substantially random manner, thus reducing susceptibility to interference from spurious electromagnetic spectra.

U.S. Patent No. 4,700,022, Salvador, describes an array of detecting conductive strips, each laid between resistive emitting strips. The finger actually makes electrical contact from an emitting strip to detecting strip. Touch location is determined from resistance variation (as with Meadows '461 and '061 above) in the strip contacted by the finger. Averages are taken of a certain number of synchronous samples. A design formula is presented to choose a sampling frequency so that it is not a multiple of the most undesired predetermined interfering signal. No suggestion is made that sampling frequency is adjusted or adapts automatically.

In U.S. Patent No. 5,305,017, Gerpheide, touch location is determined by true capacitance variation, instead of resistance variation, using a plurality of electrode strips forming virtual electrodes. This approach eliminates the necessity of a coating having uniform resistance across a display screen. However, such a capacitance-based detection device may suffer

from electrical background interference from its surroundings, which is coupled onto the sensing electrodes and interferes with position detection. These spurious signals cause troublesome interference with the detection of finger positioning. The device operator may even act as an antenna for electrical interference which may cause a false charge injection or depletion from the detecting electrodes.

Accordingly, there is a need for a touch detection system which has the following characteristics:

(1) the touch location is determined without the need of resistance variation so as to avoid the high cost of requiring uniform resistance during fabrication;

(2) the touch location is measured in a manner independent of resistance of the electrodes or their connecting wiring, thus broadening the range of materials and processes which may be used for fabrication; and

(3) electrical interference signals are rejected and eliminated from the detection system regardless of their frequency and without requiring possibly expensive nulling apparatus.

SUMMARY OF THE INVENTION

The present invention employs a touch location device having true capacitance variation by using insulated electrode arrays to form virtual electrodes. The capacitance variation is measured by means independent of the resistance of the electrodes, so as to eliminate that parameter as a fabrication consideration. The electrical interference is eliminated regardless of frequency to provide a clear detection signal.

An illustrative embodiment of the present invention includes an electrode array for developing capacitances which vary with movement of an object (such as finger, other body part, conductive stylus, etc.) near the

array, a synchronous capacitance measurement element which measures variation in the capacitances, such measurements being synchronized with a reference frequency signal, and a reference frequency signal generator for generating a reference frequency signal which is not coherent with electrical interference which could otherwise interfere with capacitance measurements and thus position location.

Interference rejection is carried out by generating a reference frequency signal whose frequency is different from the interference frequency. Alternately, the reference signal is generated with random frequencies so as not to be coherent with the interference frequencies and thus the electrical interference is effectively rejected.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a block diagram of a capacitance variation position measuring device made in accordance with the principles of the present invention;

FIG. 2A is a plan view of one illustrative embodiment of the electrode array shown in FIG. 1;

FIG. 2B is a side, cross-sectional view of one illustrative embodiment of the electrode array of FIG. 2A;

FIG. 3A is a side, cross-sectional view of another embodiment of the electrode array of FIG. 1;

FIG. 3B is a plan view of the electrode array of FIG. 3A;

FIG. 4 is a schematic of one embodiment of the synchronous electrode capacitance measurement device of FIG. 1;

FIG. 5 is a schematic of another embodiment of the synchronous electrode capacitance measurement device of FIG. 1;

FIGS. 6A-6D are circuit diagrams of alternative embodiments of the capacitance measurement elements shown in FIGS. 4 and 5;

FIG. 7 is a block diagram of one embodiment of the reference frequency generator shown in FIG. 1; and

FIG. 8 is a block diagram showing an alternative embodiment of the reference frequency generator shown in
5 FIG. 1.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

FIG. 1 shows the essential elements of a capacitance variation finger (or other conductive body or non-body part) position sensing system 10, made in
10 accordance with the invention. An electrode array 12 includes a plurality of layers of conductive electrode strips. The electrodes and the wiring connecting them to the device may have substantial resistance, which permits a variety of materials and processes to be used
15 for fabricating them. The electrodes are electrically insulated from one another. Mutual capacitance exists between each two of the electrodes, and stray capacitance exists between each of the electrodes and ground. A finger positioned in proximity to the array
20 alters these mutual and stray capacitance values. The degree of alteration depends on the position of the finger with respect to electrodes. In general, the alteration is greater when the finger is closer to the electrode in question.

25 A synchronous electrode capacitance measurement unit 14 is connected to the electrode array 12 and determines selected mutual and/or stray capacitance values associated with the electrodes. To minimize interference, a number of measurements are performed by
30 unit 14 with timing synchronized to a reference frequency signal provided by reference frequency generator 16. The desired capacitance value is determined by integrating, averaging, or in more general terms, by filtering the individual measurements made by
35 unit 14. In this way, interference in the measurement is substantially rejected except for spurious signals

having strong frequency spectra near the reference frequency.

The reference frequency generator 16 attempts to automatically select and generate a reference frequency which is not coherent with the most undesirable frequency of spurious signals. This approach substantially eliminates interference even though its frequency is likely to be initially unknown and may even change during operation.

10 A position locator 18 processes the capacitance measurement signal from the synchronous electrode capacitance measurement unit 14 and provides position signals for use by a host computer, for example, and to the reference frequency generator 16. The position
15 locator unit 18 determines finger position signals based on the capacitance measurements. Several different systems are commonly known in the art for determining finger position based on measurements of capacitance associated with electrodes in an array.
20 Position locators may provide one-dimensional sensing (such as for a volume slider control), two-dimensional sensing with contact determination (such as for computer cursor control), or full three-dimensional sensing (such as for games and three-dimensional computer graphics.)
25 An example of a prior art position locator unit is shown in the Gerpheide '017 patent mentioned above, as units 40 and 50 of FIG. 1 of the patent.

Electrode Array:

FIG. 2A illustrates the electrodes in a preferred
30 electrode array 12, together with a coordinate axes defining X and Y directions. One embodiment includes sixteen X electrodes and twelve Y electrodes, but for clarity of illustration, only six X electrodes 20 and four Y electrodes 22 are shown. It is apparent to one
35 skilled in the art how to extend the number of electrodes. The array is preferably fabricated as a multilayer printed circuit board 24. The electrodes are

etched electrically conductive strips, connected to vias 26 which in turn connect them to other layers in the array. Illustratively, the array 12 is approximately 65 millimeters in the X direction and 49 millimeters in the Y direction. The X electrodes are approximately 0.7 millimeters wide on 3.3 millimeter centers. The Y electrodes are approximately three millimeters wide on 3.3 millimeter centers.

FIG. 2b illustrates the electrode array 12 from a side, cross-sectional view. An insulating overlay 21 is an approximately 0.2 millimeters thick clear polycarbonate sheet with a texture on the top side which is comfortable to touch. Wear resistance may be enhanced by adding a textured clear hard coating over the top surface. The overlay bottom surface may be silk-screened with ink to provide graphics designs and colors.

The X electrodes 20, Y electrodes 22, ground plane 25 and component traces 27 are etched copper traces within a multilayer printed circuit board. The ground plane 25 covers the entire array area and shields the electrodes from electrical interference which may be generated by the parts of the circuitry. The component traces 27 connect the vias 26 and hence the electrodes 20, 22, to other circuit components of FIG. 1. Insulator 31, insulator 32 and insulator 33 are fiberglass-epoxy layers within the printed circuit board 24. They have respective thicknesses of approximately 1.0 millimeter, 0.2 millimeters and 0.1 millimeters. Dimensions may be varied considerably as long as consistency is maintained. However, all X electrodes 20 must be the same size, as must all Y electrodes 22.

One skilled in the art will realize that a variety of techniques and materials can be used to form the electrode array. For example, FIG. 3A illustrates an alternative embodiment in which the electrode array includes an insulating overlay 40 as described above.

Alternate layers of conductive ink 42 and insulating ink 43 are applied to the reverse surface by a silk screen process. The X electrodes 45 are positioned between the insulating overlay 40 and X electrode conductive ink layer 42. Another insulating ink layer 43 is applied below layer 42. The Y electrodes 46 are positioned between insulating ink layer 43 and conductive ink layer 44. Another insulating ink layer 47 is applied below conductive ink layer 44, and ground plane 48 is affixed to Y electrode conductive ink layer 47. Each layer is approximately 0.01 millimeters thick.

The resulting array is thin and flexible, which allows it to be formed into curved surfaces. In use it would be laid over a strong, solid support. In other examples, the electrode array may utilize a flexible printed circuit board, such as a flex circuit, or stampings of sheet metal or metal foil.

A variety of electrode geometries and arrangements are possible for finger position sensing. One example is shown in FIG. 3b. This is an array of parallel electrode strips 50 for one-dimensional position sensing which could be useful as a "slider volume control" or "toaster darkness control". Other examples include a grid of diamonds, or sectors of a disk.

It is desired that the electrode array of the present invention be easily fabricated by economical and widely available printed circuit board processes. It is also desired to allow use of various overlay materials selected for texture and low friction, upon which logo art work and coloration can be economically printed. A further preference is that the overlay may be custom printed separately from fabrication of the electrode-containing part of the array. This allows an economical standardized mass production of that part of the array, and later affixing of the custom printed overlay.

Synchronous Electrode Capacitance Measurement:

FIG. 4 shows one embodiment of the synchronous electrode capacitance measurement unit 14 in more detail. The key elements of the synchronous electrode capacitance measurement unit 14 are (a) an element for producing a voltage change in the electrode array synchronously with a reference signal, (b) an element producing a signal indicative of the displacement charge thereby coupled between electrodes of the electrode array, (c) an element for demodulating this signal synchronously with the reference signal, and (d) an element for low pass filtering the demodulated signal. Unit 14 is coupled to the electrode array, preferably through a multiplexor or switches. The capacitances to be measured in this embodiment are mutual capacitances between electrodes but could be stray capacitances of electrodes to ground or algebraic sums (that is sums and differences) of such mutual or stray capacitances.

FIG. 4 shows one specific embodiment of a synchronous electrode capacitance measurement unit 14 connected to the electrode array 12, in which algebraic sums of mutual capacitances between electrodes are measured. The components are grouped into four main functional blocks. A virtual electrode synthesis block 70 connects each of the X electrodes to one of the wires CP or CN, and each of the Y electrodes to one of the wires RP or RN. The electrodes are selectively connected to the wires by switches, preferably CMOS switches under control of the position locator apparatus 18 (FIG. 1) to select appropriate electrodes for capacitance measurement. (See Gerpheide '017 which describes such electrode selection by signal S of FIG. 1 of the patent.) All electrodes connected to the CP wire at any one time are considered to form a single "positive virtual X electrode". Similarly, the electrodes connected to CN, RP, and RN form a "negative virtual X electrode", a "positive virtual Y electrode", and a "negative virtual Y electrode", respectively.

The reference frequency signal is preferably a digital logic signal from the reference frequency generator 16 (FIG. 1). The reference frequency signal is supplied to unit 14 via an AND gate 72 also having a
5 "drive enable" input, supplied by the reference frequency generator 16 (FIG. 1). The AND gate output feeds through inverter 74 and noninverting buffer 76 to wires RP and RN respectively which are part of a capacitive measurement element 78. In the preferred
10 embodiment, the drive enable signal is always TRUE, to pass the reference frequency signal. In further preferred embodiments, it is asserted FALSE by the reference frequency generator when interference evaluation is to be performed as described later. When
15 the drive enable signal is FALSE, the drive signal stays at a constant voltage level. When the drive signal is TRUE, it is a copy of the reference frequency signal.

The capacitance measurement element 78 contains a differential charge transfer circuit 80 as illustrated
20 in FIG. 4 of Gerpheide, U.S. Patent 5,349,303, incorporated herein by reference. Capacitors Cs1 and Cs2 of FIG. 4 of that patent correspond to the stray capacitances of the positive and negative virtual electrodes to ground. The CHOP signal of that FIG. 4 is
25 conveniently supplied in the present invention as a square wave signal having half the frequency of the reference frequency signal; as generated by the divide-by-2 circuit 81 shown herein. As described in the Gerpheide '303 patent, the circuit maintains CP and CN
30 (lines 68 and 72 therein) at a constant virtual ground voltage.

The capacitance measurement element 78 also contains a non-inverting drive buffer 76 which drives RN and negative virtual Y electrodes to change voltage
35 levels copying the drive enable signal transitions. The inverting buffer 74 drives RP and the positive virtual Y electrodes to change voltage levels opposite the drive

enable signal transitions. Since CP and CN are maintained at virtual ground, these voltage changes are the net voltage changes across the mutual capacitances which exist between virtual Y and virtual X electrodes.

5 Charges proportional to these voltage changes multiplied by the appropriate capacitance values are thereby coupled onto nodes CP and CN (the "coupled charges"). The charge transfer circuit therefore supplies a proportional differential charges at outputs Qo1 and

10 Qo2, which are proportional to the coupled charges and thus to the capacitances.

In short, this differential charge is a proportionality factor K times the "balance" L, which is a combination of these capacitances given by the

15 equation:

$$L = M(xp, yn) + M(xn, yp) - M(xp, yp) - M(xn, yn)$$

where M(a,b) is the notation for the mutual capacitance between virtual electrode "a" and virtual electrode "b". Changes in balance are indicative of finger position

20 relative to virtual electrode position as described in Gerpheide, U.S. Patent 5,305,017. The proportionality factor K has a sign which is the same as the drive enable signal transition direction.

Referring again to FIG. 4, the synchronous

25 electrode capacitance measurement element 78 is connected via lines carrying charges Qo1 and Qo2 to a synchronous demodulator 82 which may be a double-pole double-throw CMOS switch 84 controlled by the reference frequency signal. The synchronous demodulator 82, which

30 among other things functions to rectify the charges Qo1 and Qo2, is connected to a low-pass filter 86 which may be a pair of capacitors C1, C2 configured as an integrator for differential charges. (An integrator illustratively is a low pass filter with 6db per octave

35 frequency roll off.) Charges Qo1 and Qo2 are integrated onto capacitors C1 and C2, respectively, when the reference frequency signal has just transitioned

positive, and K is positive. The charges are integrated onto opposite capacitors when K is negative. In this way, a differential charge proportional to the balance L is accumulated on $C1$ and $C2$.

5 FIG. 5 shows another embodiment of the synchronous electrode capacitance measurement unit 14. In this embodiment, each electrode in an electrode array 90 is connected to a dedicated capacitance measurement element 92, each of which is connected to a synchronous
10 demodulator 94 and then to a low pass filter 96. This configuration has the advantage of continuously providing capacitance measurements for each electrode, whereas the prior preferred embodiment measures a single configuration of electrodes at any one time. The
15 disadvantage of the embodiment of FIG. 5 is the greater expense which may be associated with the duplicated elements. This is a common tradeoff between providing multiple elements to process measurements at the same time versus multiplexing a single element to process
20 measurements sequentially. There is obviously a wide spectrum of variations applying this trade off.

Also, many of the elements can be implemented in digital form using analog-digital converters and digital signal processing. While the preferred embodiments
25 currently use substantial analog processing, future digital processing costs may be expected to become relatively cheaper.

FIG. 6 provides a number of preferred alternatives for the capacitance measurement element 78 (FIG. 4) or
30 92 (FIG. 5). FIGS. 6A and 6B show circuits adapted for measuring mutual capacitances between electrodes (which may be physical or virtual electrodes), represented by C_{mp} , C_{mn} , and C_m . FIGS. 6C and 6D show circuits adapted for measuring electrode capacitance to ground
35 represented by C_g . Each of these provides an output voltage change indicative of the capacitance being

measured. These voltage changes are given by the following formulas:

For FIG. 6A: $\Delta V_{out} = \Delta V_{drive} \times (C_{mp} - C_{mn}) / C_r$

For FIG. 6B: $\Delta V_{out} = \Delta V_{drive} \times C_m / C_r$

5 For FIG. 6C: $\Delta V_{out} = \Delta V_{drive} \times C_g / (C_g + C_r)$

For FIG. 6D: $\Delta V_{out} = \Delta V_{drive} \times (C_g + C_r) / C_g$

The formulas depend on a known reference capacitance represented by C_r and a known drive voltage change represented by ΔV_{drive} . Further capacitance
10 measurement elements may be based on charge balance techniques as described in Meyer, U.S. Patent 3,857,092. Synchronous demodulators may be implemented using an analog or digital multiplier, or a "double-balanced mixer" integrated circuit (such as part number LM1496)
15 from National Semiconductor Company. There are different implementations known in the art for low pass filter elements, such as switched capacitor integrators and filters, high-order analog filters, and digital filters.

20 Reference Frequency Generator:

FIG. 7 illustrates a preferred embodiment of reference frequency generator 16 (FIG. 1). The generator observes position signals to evaluate the extent of interference at some reference frequency. In
25 the event that substantial interference is detected, the generator 16 selects a different frequency for further measurements. The generator 16 seeks to always select a reference frequency away from frequencies which have been found to result in measurement interference, as
30 described below.

The generator 16 includes an oscillator 100 which is, for example, set at four MHz, driving a microcontroller 102 and a divide-by-(M+N) circuit 104. Value N is a fixed constant, approximately 50. Value M
35 is specified by the microcontroller 102 to be, for example, one of four values in the range 61 KHz to 80 KHz as specified by the microcontroller 102.

The microcontroller 102 performs the functions of interference evaluation 106 and frequency selection 108. It may perform other functions associated with the system such as position location. The preferred
 5 interference evaluation function 106 produces a measure of the interference in the position signals generated by the position location unit 18 (FIG. 1). This is based on the principle that interference produces a spurious, relatively large magnitude high-frequency component of
 10 a position signal, and operates according to the following code description. It assumes position data points X, Y, and Z occur approximately every ten milliseconds. In brief, it calculates an interference measure, IM, as the sum of the absolute values of the
 15 second differences of X and Y together with the absolute values of the first differences of Z over 32 data points. Differencing a stream of data has the effect of applying a high-pass filter to it.

In detail, for each data point the interference
 20 evaluation function 106 executes the following steps, where ABS() means the absolute value function:

```

      XD=X-XLAST      ;computes first differences
      YD=Y-YLAST
      ZD=Z-ZLAST
  25      XDD=XD-XDLAST      ;computes second
      differences
      YDD=YD-YLAST
      IM = IM + ABS(XDD) + ABS(YDD) + ABS(Z)      ;sum
      IF EVERY 32ND SAMPLE
  30          {EXECUTE FREQUENCY SELECT FUNCTION 108
              (See description below)
              IM = 0}
      XLAST=X          ;move current values to
      last
  35      YLAST=Y
      ZLAST=Z
      XDLAST=XD
  
```

YDLAST=YD

In another embodiment, the interference evaluation function 106 is not based on position signals. Instead the function asserts the drive enable signal described above to a FALSE state and reads a resulting synchronous capacitance measurement. This measures charge coupled to the electrodes when no voltage is being driven across the electrodes by the apparatus. Such charge must be the result of interference, and so this interference (from spurious signals) is directly measured. This is another way to generate the interference measure, IM.

The preferred frequency select function 108 generates a table of historical interference measurements for each frequency which may be selected. On system initialization, each entry is set to zero. Thereafter, the frequency select function is activated approximately every 32 data points by the interference evaluation function 106. The current interference measure, IM, is entered as the entry for the currently selected frequency in the table. Then all table entries are scanned. The frequency having the lowest interference measure entry is selected as the new current frequency, and the corresponding M value is sent to the divide-by-(M+N) element 104. Approximately every 80 seconds, every entry in the table is decremented by an amount corresponding to approximately 0.05 mm of position change. In this way, if a frequency is flagged as "bad" by having strong interference one time, it will not be flagged as "bad" permanently.

The functions described above for the different embodiments could be carried out by a microprocessor such as part no. MC 68HC705P6 manufactured by Motorola, Inc. serving as the microcontroller 102.

FIG. 8 shows an alternate preferred embodiment of the reference frequency generator 16 (FIG. 1). It generates a reference frequency signal that varies randomly. Each cycle of the signal has a different and

substantially random period. It is extremely unlikely that a spurious signal would coherently follow the same sequence of random variation. Hence the spurious signal is substantially rejected by capacitance measurements
5 synchronous to the reference frequency. The degree of rejection is not as great as in the former embodiment, but the generator is simpler because interference evaluation and frequency selection functions are not needed.

10 The generator of FIG. 8 includes an oscillator 110 and a divide-by-(N+M) circuit 112. The value M supplied to the divider comes from a pseudo-random number generator (PRNG) 114 which generates numbers in the range 0 to 15. Each cycle of the reference frequency
15 clocks the PRNG 114 to produce a new number. PRNGs are well known in the art.

For either embodiment in FIGS. 7 or 8, the range of values for M in relation to the value of N can be increased or decreased to give a greater or lesser range
20 of possible frequencies. The value of N or the oscillator frequency can be adjusted to change the maximum possible frequency. A phase-locked frequency synthesizer such as the Motorola MC145151-2, or a voltage controlled oscillator driven by a D/A converter,
25 could also preferably be employed instead of the divide-by-(M+N) circuit.

It should be understood that other variations of the preferred embodiments described above fall within the scope of this invention. Such variations include
30 different electrode array geometry, such as a grid of strips, a grid of diamonds, parallel strips and various other shapes. Also included are different variations of electrode array fabrication, such as printed circuit board (PCB), flex PCB, silk screen, sheet or foil metal
35 stampings. Variations of the kinds of capacitance utilized are included, such as full balance (see Gerpheide '017), stray, mutual, half balance.

The above description has provided certain preferred embodiments in accordance with this invention. It is apparent by those skilled in the art that various modifications can be made within the spirit and scope of the invention, which are included within the scope of the following claims.

CLAIMS

What is claimed is:

1. A capacitance-based proximity sensor for locating the position of an object while rejecting
5 electrical interference, comprising:

(a) an electrode array for forming capacitances which vary with movements of the object,

(b) measurement means coupled to the electrode array for measuring the capacitances synchronously with
10 a reference signal, and

(c) generator means for supplying a reference signal to the measurement means, said reference signal having a frequency which is not coherent with the frequency of the electrical interference.
15

2. The proximity sensor of Claim 1 wherein the generator means comprises means for evaluating the electrical interference and for producing a reference signal whose frequency is different from the frequencies
20 of the electrical interference.

3. The proximity sensor of Claim 2 wherein the evaluating means includes means for storing a table of frequencies of selected reference signals and measures
25 of electrical interference IM for each of these frequencies, and for producing a reference signal whose frequency has the lowest IM associated therewith.

4. The proximity sensor of Claim 1 wherein the
30 generator means comprises oscillator means for producing the reference signal, and means for randomly varying the frequency of the reference signal produced by the oscillator means.

35 5. The proximity sensor as in Claim 4 wherein the varying means comprises means for changing the frequency of the reference signal in proportion to a supplied

number, and a pseudo-random number generator for supplying numbers successively to the changing means.

5 6. The proximity sensor as in Claim 1 further including object locator means responsive to the measurement means for producing a position signal, having a high frequency component, indicating the position of the object relative to the electrode array, and wherein said generator means comprises
10 evaluation means responsive to the object locator means for determining the magnitude of the high frequency component of the position signal, and
 means responsive to the evaluation means for changing the frequency of the reference signal when the
15 magnitude of the high frequency component of the position signal exceeds a predetermined value.

 7. The proximity sensor as in Claim 1 wherein said measurement means comprises
20 driver means for developing, synchronously with the reference signal, voltage changes on the electrode array,
 charge measuring means for measuring, synchronously with the reference signal, charges coupled to the
25 electrode array and thus capacitance,
 means for selectively inhibiting the driver means from developing voltage changes, the coupled charge measurements made during inhibition of the driver means representing an interference measure IM, and
30 wherein said generator means includes means for changing the frequency of the reference signal when the interference measure IM exceeds a predetermined level.

 8. The proximity sensor as in Claim 7 wherein the
35 generator means further includes means for storing a table of frequencies of reference signals and associated interference measures IM made for reference signals with

each of such frequencies, and for producing a reference signal whose frequency has the lowest interference measure IM associated therewith.

5

9. The proximity sensor of Claim 1 wherein the electrode array comprises a plurality of first electrode strips spaced apart from each other in a first array, and a plurality of second electrode strips spaced apart from each other and in close proximity with the first electrode strips.

10. The proximity sensor of Claim 9 wherein the measurement means includes

15 a driver means for developing, synchronously with the reference signal, voltage changes on the electrode array,

a charge transfer means coupled to the electrode array for producing synchronously with the frequency of the reference signal, measurement signals representing charges coupled onto the electrode array as a result of the voltage changes,

20 synchronous demodulator means coupled to the charge transfer means for rectifying the measurement signals synchronously with the reference signal, and

low pass filter means coupled to the synchronous demodulator means for producing signals representing the average DC values of the rectified signals, and thus representing the capacitances of the electrode array.

30

11. The proximity sensor of Claim 10 wherein the measurement means includes a plurality of capacitance measurement elements, each being connected to a respective electrode strip.

35

12. The proximity sensor of Claim 11 further comprising a plurality of synchronous demodulation

elements, each connected to a respective capacitance measurement element.

13. The proximity sensor of Claim 1 further
5 including a position locator means connected to the output of the measurement means for providing a position signal representative of the location of the object relative to the electrode array.

10 14. A capacitance-based touch detection system for rejecting interference and developing data by sensing the position of an object relative to a touch pad, comprising:

(a) an electrode array for generating a
15 capacitance adjacent to the touch pad,

(b) means for measuring the variation of capacitance adjacent the touch pad as the object is moved relative to the pad, and in synchronization with a reference frequency signal, and

20 (c) means for generating a reference frequency signal for supply to the measuring means, the frequency of the reference frequency signal being remote from the frequency of the interference, to effectively reject said interference.

25

15. The detection system of Claim 14 wherein the reference frequency generator means comprises means for evaluating the frequency of the interference and selecting a reference frequency signal whose frequency
30 is remote from the interference frequency.

16. The detection system of Claim 14 wherein the reference frequency generator means comprises an oscillator and a pseudo-random number generator coupled
35 to the oscillator to generate reference frequency signals whose frequencies are random.

17. The detection system of Claim 14 wherein the electrode array comprises first and second electrode sets spaced from each other to develop a capacitance for the touch pad.

5

18. The detection system of Claim 17 wherein the first and second set of electrodes are generally orthogonal to each other to form virtual electrodes to provide capacitance.

10

19. The detection system of Claim 14 wherein the measuring means comprises a capacitive measurement element coupled to the electrode array, a synchronous demodulator coupled to the capacitive measurement element, and a low-pass filter coupled to the demodulator.

15

20. A method of sensing the position of an object on an electrode array comprising the steps of:

20

(a) generating capacitances on the array which vary with movement of the object,

(b) measuring the capacitances on the array synchronously with the frequency of a reference signal, and

25

(c) generating a reference signal having a frequency which is not coherent with the frequencies of the electrical interference affecting the capacitances.

30

21. The method of Claim 20 and further including producing a signal indicating the position of the object relative to the electrode array.

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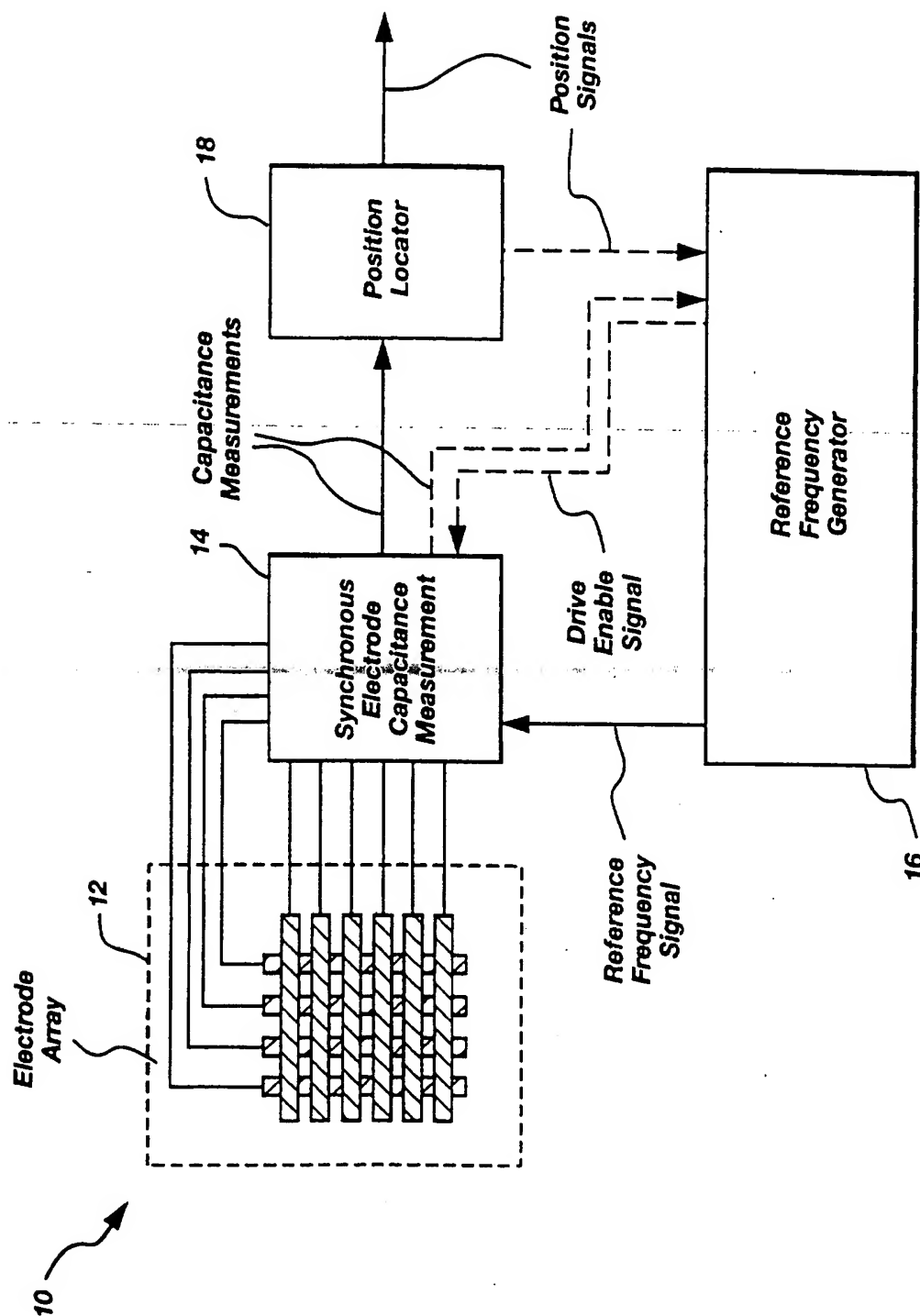


Fig. 1

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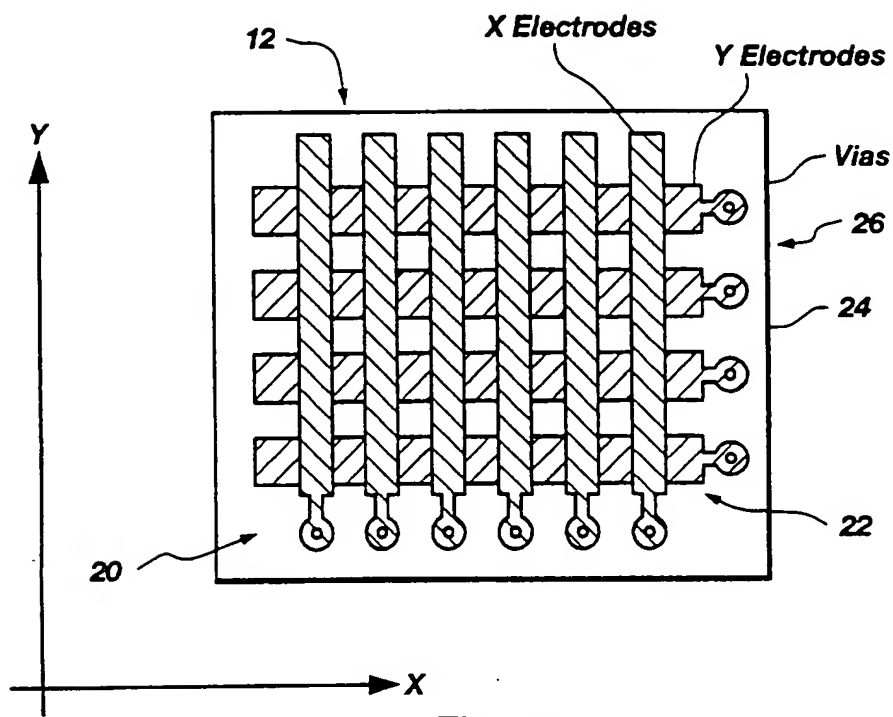


Fig. 2a

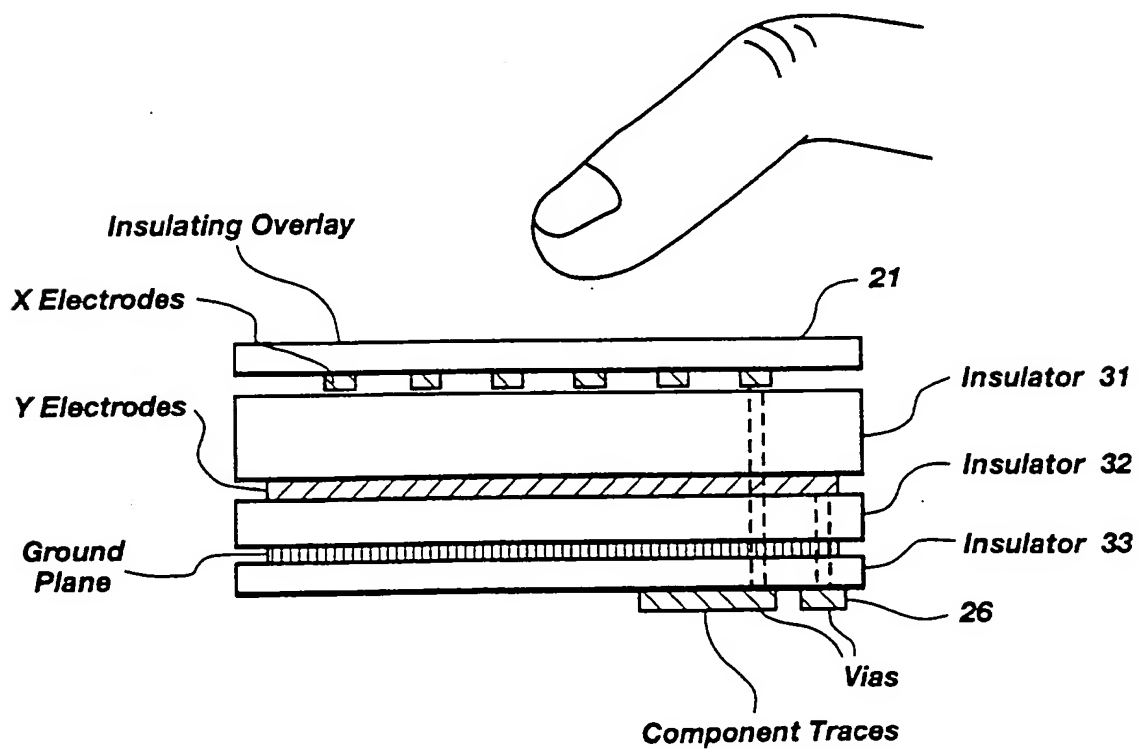


Fig. 2b

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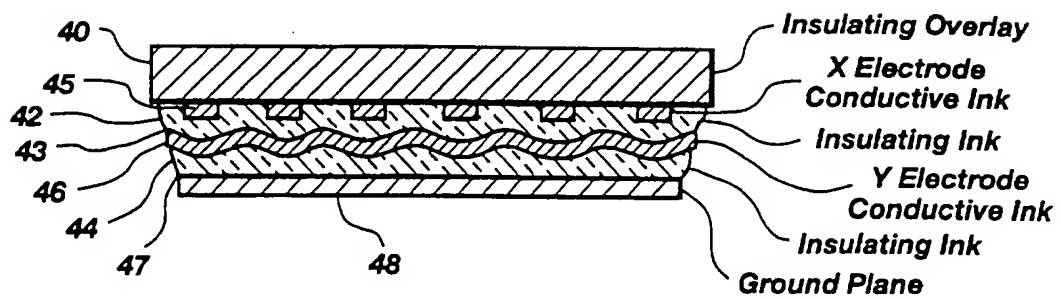


Fig. 3a

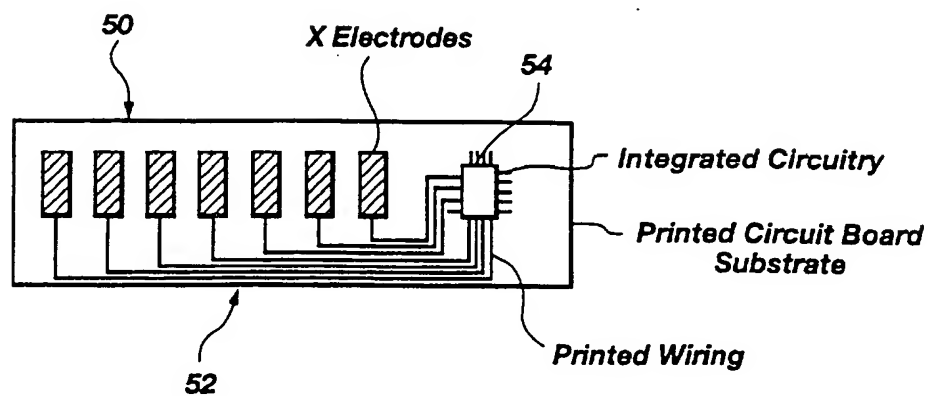


Fig. 3b

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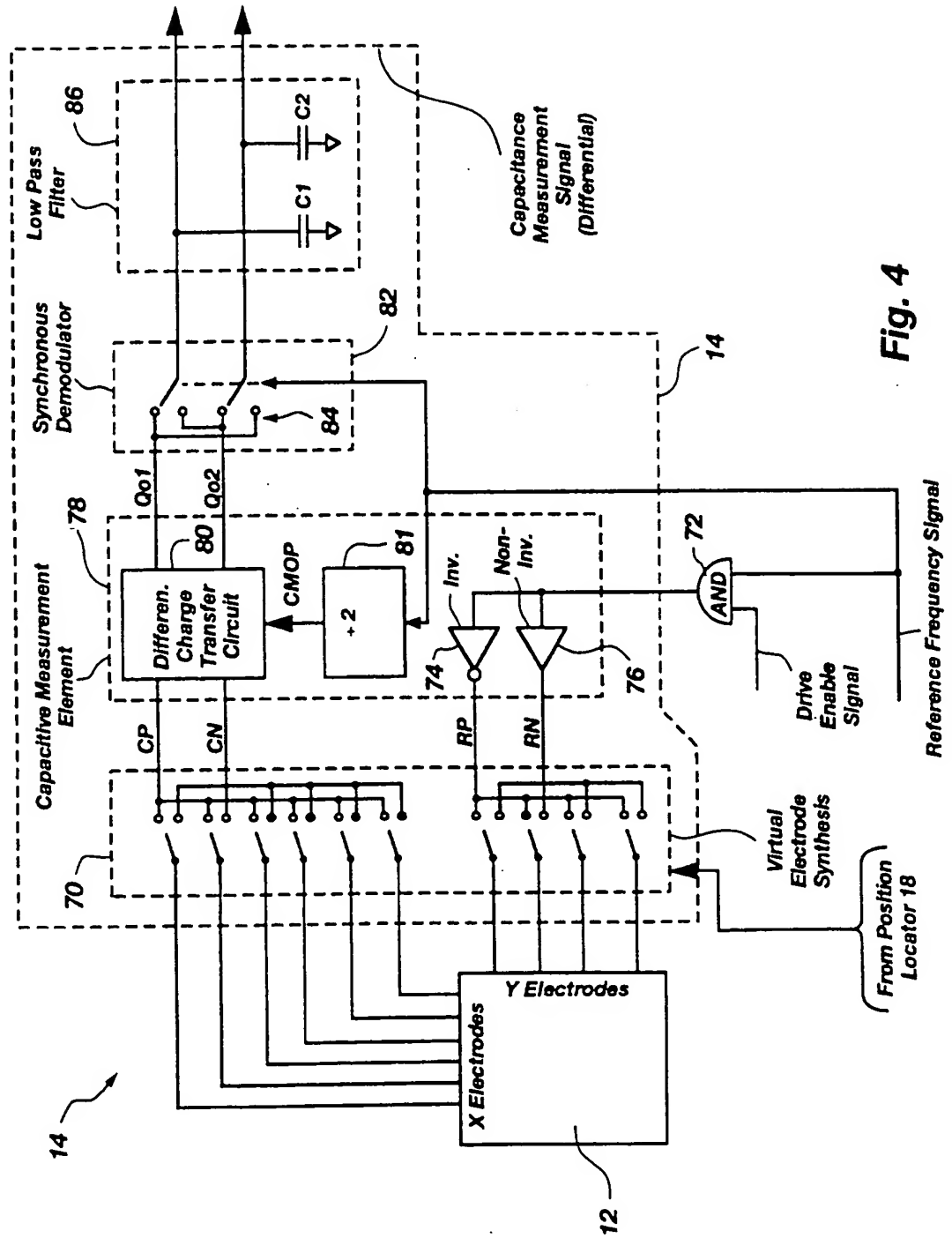


Fig. 4

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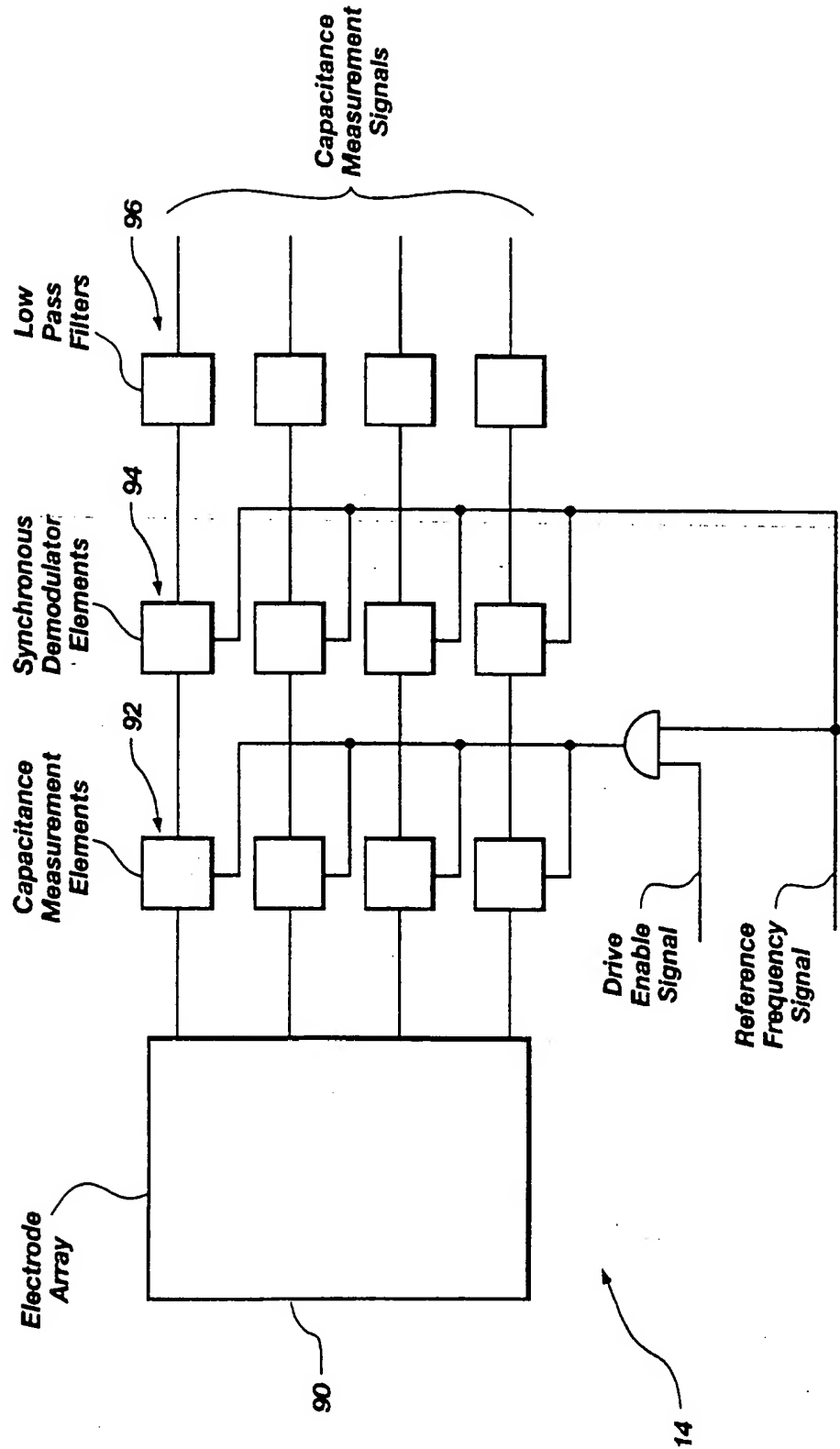


Fig. 5

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Fig. 6a

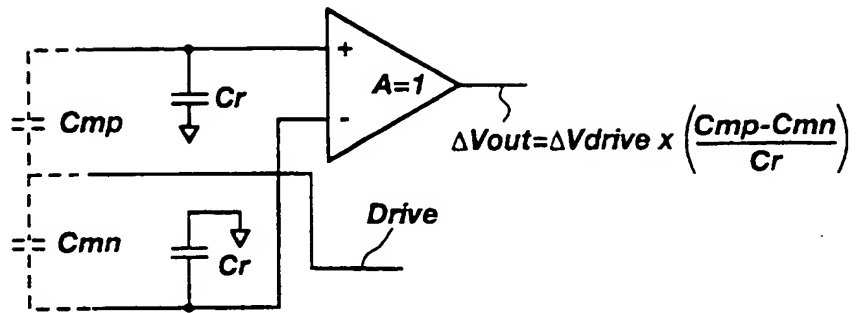


Fig. 6b

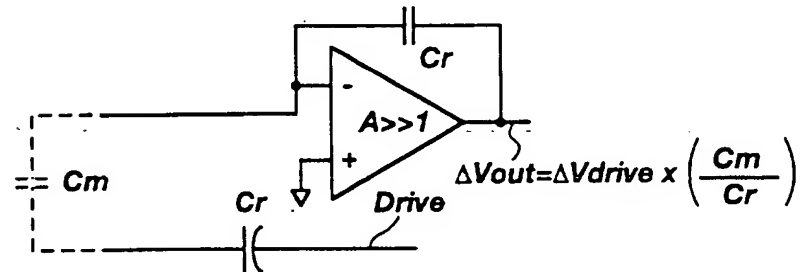


Fig. 6c

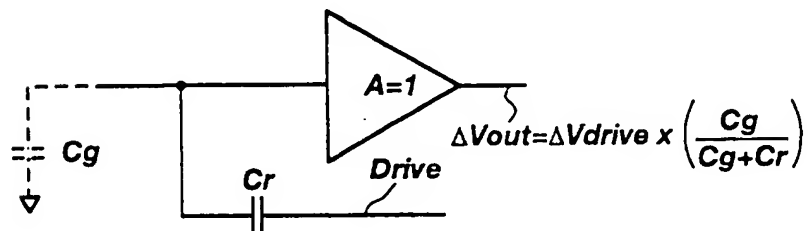
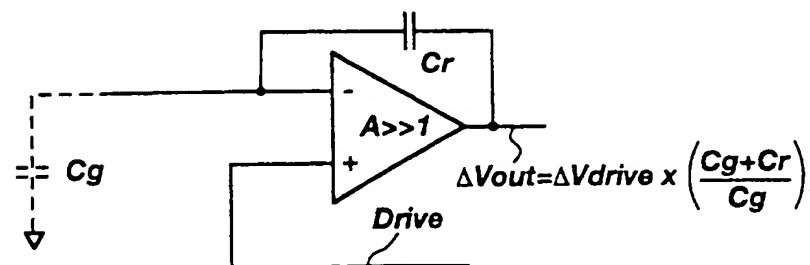


Fig. 6d



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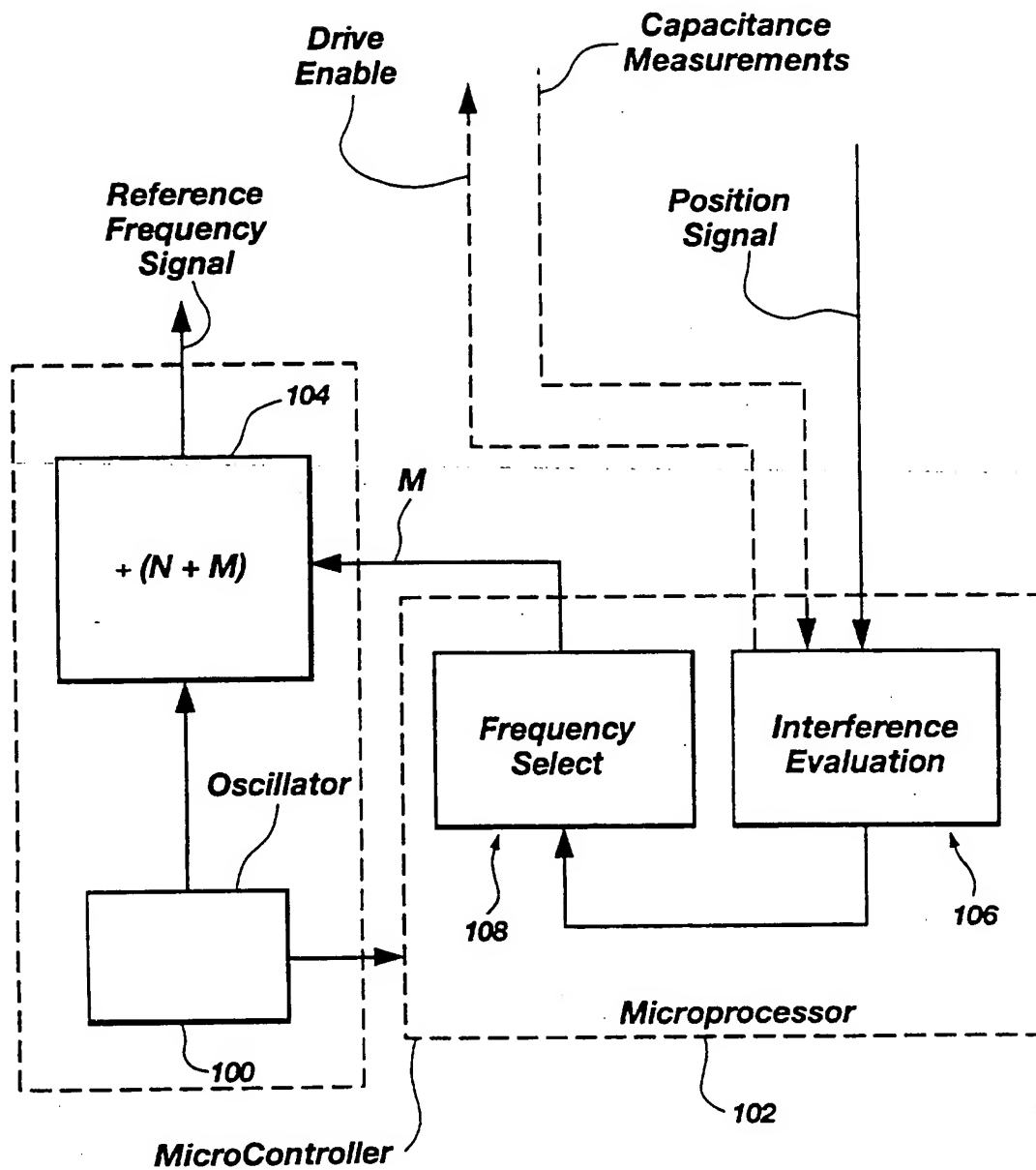
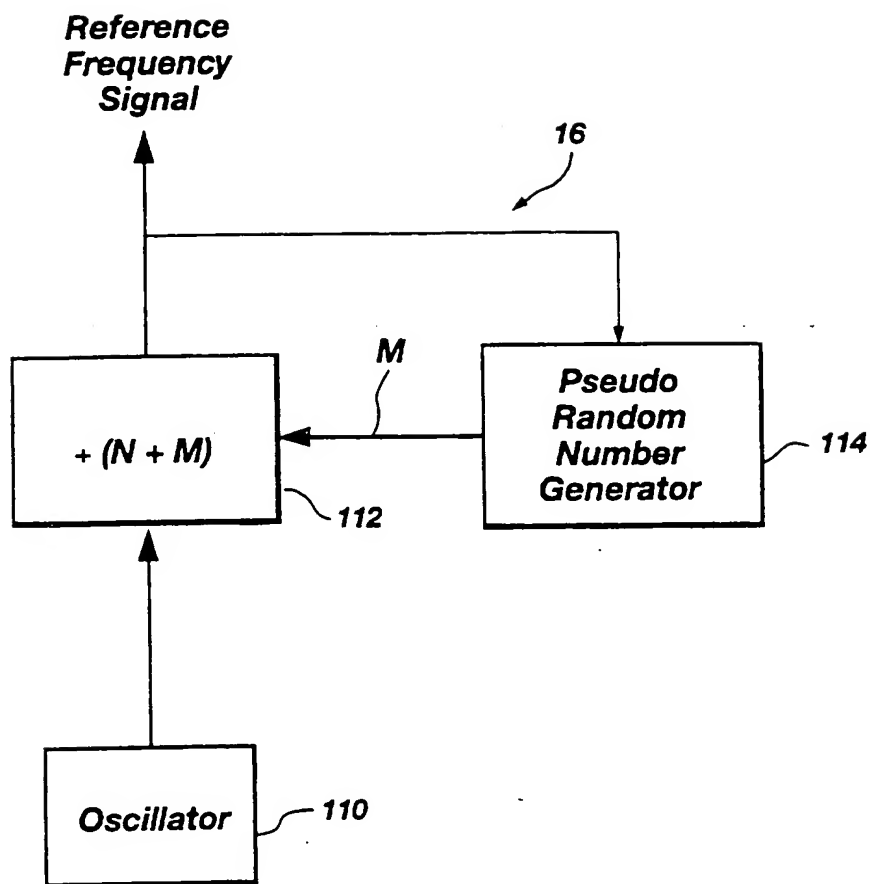


Fig. 7

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**Fig. 8**

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US95/15832

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) : G08C 21/00

US CL : 178/18,19; 345/173, 174

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 178/18,19, 345 173 174, 168, 328/5, 342/16

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
noneElectronic data base consulted during the international search (name of data base and, where practicable, search terms used)
NONE

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US, A, 5,053,757 (MEADOWS) 01 October 1991, see col.26, col. 19 and col. 20.	1,2,9,13-15,17-21
Y	US, A, 4,845,682 (BOOZER ET AL.) 04 July 1989, see figure 5 and summary of the invention.	4,5,16
A	US, A, 4,237,421 (WALDRON) 02 December 1980, see Abstract.	1-21
A	US, A, 4,476,463 (NG ET AL.) 09 October 1984, see abstract.	1-21

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Further documents are listed in the continuation of Box C

☐

See patent family annex.

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document defining the general state of the art which is not considered to be part of particular relevance

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L

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O

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T

later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

X

document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

Y

document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

N

document member of the same patent family

Date of the actual completion of the international search

07 FEBRUARY 1996

Date of mailing of the international search report

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Name and mailing address of the ISA/US
Commissioner of Patents and Trademarks
Box PCT
Washington, D.C. 20231

Facsimile No. (703) 305-3230

Authorized officer

PAUL LOOMIS

Telephone No. (703) 305-4766